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TITLE: FMIT BEAMSTOP

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FMIT BEAMSTOP*

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Summary

The Fusion Material Irradiation Test (FMIT) and FMIT prototype beamstops provide several unique design challenges. The prototype beamstop must be capable of handling 500 kW of continuous power; the FMIT beamstop must handle 3500 kW of power in a pulsed form. The particle involved is H_2^+. These beamstops must convert these energies to heat that is carried away by cooling water, while being contained in a relatively compact package, tolerant of changes in beamspot shape and size. The range of the beam is less than 0.1 mm in the prototype beamstop and less than 3 mm in the FMIT beamstop; thus energy cannot be spread over the depth of the absorbing material very readily. Long-term irradiation of the materials used must be kept low, to minimize maintenance problems, requiring consideration of materials. Material distortion from thermal effects also must be considered.

Incoming Beam

The prototype beam actually has more average power than the final version because in the final version, the beam is pulsed at a 2% duty factor. In the prototype, the beam has an energy of 5 MeV at 100 mA for an average power of 500 kW. This beam will fall continuously (100% duty factor) while the prototype is in operation, and the prototype beamstop must be capable of accepting the beam for many hours or days. The incoming particles will be H_2^+, and the penetration depth in the graphite facing material is less than 0.1 mm (0.004 in.). It is likely that the prototype beamstop also will be used as a beamstop for the prototype radio-frequency quadrupole (RFQ), with an incoming beam of 2 MeV at 100 mA, for a 200-kW power.

In the final FMIT version, deuterons will be used to generate neutrons by impinging on the lithium target. However, in the final version the beamstop will be used only during tuning; and because the beam is diverted from the lithium target, it is intended to use H_2^+ during tuning. Thus, only the natural fraction of the deuterium contained within H_2^+ hits the beam stop. The incoming beam has an energy of 35 MeV at 100 mA. However, this occurs in 10-ms pulses, with a cycle time of 500 ms, resulting in a 2% duty factor; thus, the beam has a pulse power of 3500 kW, but an average power of only 70 kW. The beam's penetration depth is approximately 2 mm (0.085 in.) for H_2^+ in the graphite facing material.

Beamstop Configuration

Figure 1 schematically shows the prototype beamstop; Fig. 2 schematically shows the FMIT beamstop. In the prototype beamstop, the main objective is to spread the beam so that the surface does not heat excessively, and so that excessive boiling does not occur in the water-cooling passages. This is accomplished by a plate that slopes at a 5:1 angle to the incoming beam. Thus, the roughly circular incoming beam, which is spread out upstream

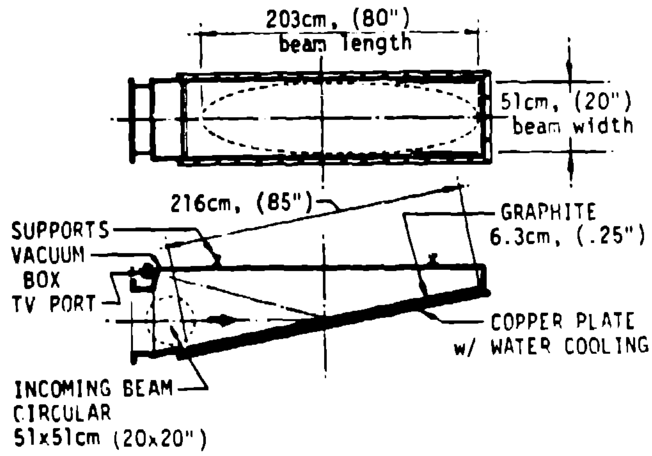

Fig. 1. Prototype beamstop.

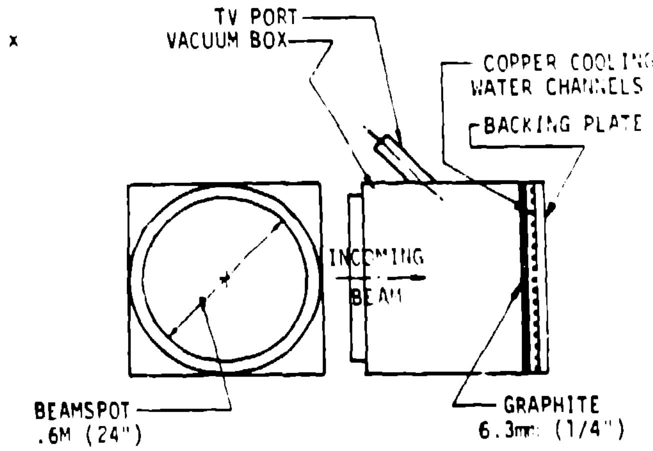

Fig. 2. FMIT Beamstop.

by a suitable diverging magnet, is projected onto the plate as an ellipse. The size of this plate is approximately 0.6 m by 2 m (2 ft x 6 ft) with the long dimension running the length of the beam.

The beam is enlarged as it passes through a series of progressively larger beam pipes. Then it enters the vacuum box, a wedge-shaped box with the sloping beamstop plate forming the diagonal side. The beamstop plate thus defines part of the vacuum boundary. The vacuum box has cooling coils on the outside to adsorb the heat from beam scatter, and heat radiation from the beamstop plate. The vacuum sealing surface encircles the the front face periphery of the plate, allowing removal of the plate from the rear, for repair. All water-cooling passages exit from the plate outside the vacuum sealing surface, thus preventing water leaks into the vacuum.

In the final FMIT version, the beamstop plate is normal to the incoming beam. This lets the beam penetrate the maximum distance into the graphite facing material so that, during a pulse, the energy is deposited over as great a depth as possible, to prevent localized heating of the surface area. In the prototype beamstop, this is not as great a

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consideration because of the steady-state nature of the beam. The vacuum box is square in this case, with one wall forming the beamstop plate. The vacuum box has cooling coils, and all water passages exit outside the vacuum sealing surface, as in the prototype case. The approximate plate size is 0.6 m by 0.6 m (2 ft by 2 ft). This plate size reflects the decreased total average power of the incoming beam, compared with the prototype. However, it also has a lower average-power density, to prevent excessive temperature excursions of the front face during a pulse.

Diagnostics

A view port is provided in both beamstops for an infrared TV camera and an array of fixed-position infrared sensors. If the beam should wander too far off center, or should focus to a higher than permissible intensity, logic is provided to shut off the beam, thus protecting the vacuum-box sides and the beamstop plate.

Facing Material

The material chosen for the beamstop plate is copper, because its excellent thermal-conductivity characteristics allow it to spread heat more uniformly around the water-cooling passages, thus avoiding hot spots in the passages. However, copper undergoes a 65 Cu (P,n) 65 Zn reaction under 2.5-MeV (or greater) H_2^+ bombardment, and the 65 Zn residual has a 244-day half-life. This means that if the beam falls directly on the copper, unacceptable irradiation will occur. Aluminum has almost as good thermal conductivity, but only slightly better irradiation properties for use in the final FMIT version, and other high thermal-conductivity materials have various other problems.

Graphite has good irradiation properties and short decay times for both cases. By retaining the copper backing material, heat still can be distributed evenly around the water; and by using graphite facing material attached to this backing, irradiation problems are reduced. After consideration, it was decided to use a high-temperature braze to bond the graphite to the copper rather than mechanical fasteners, to obtain better thermal contact.

Graphite contracts more slowly than copper upon cooling after brazing, or during a thermal cycle in operation; therefore it is likely to crack or bow the composite plate, because of thermal distortion. To alleviate these tendencies, many individual graphite tiles are used on the beamstop plate. Before being brazed onto the copper backing, an intermediate sheet of molybdenum is brazed onto the graphite tiles, then the molybdenum-backed tiles are brazed as a group onto the larger copper plate. The molybdenum serves as a stress relief for the graphite by adsorbing most of the stress.

In the final FMIT version, the temperature of the graphite fluctuates in the layers where energy is deposited because the beam is on for 10 ms, and then off for 490 ms, in a 500-ms cycle. Figure 3 shows the temperatures at (1) the front face; (2) the hottest point, 1.65 mm (0.065 in.) deep, which is slightly upstream of the Bragg Peak, at 2.15 mm (0.085 in.); and (3) the rear of the graphite plate, 6.3 mm (0.25 in.) thick. These temperature curves were obtained with the code PULSE, a one-dimensional transient finite-element code developed by R. C. Potter. These temperature fluctuations are regarded as acceptable, because the micro-crack structure of graphite arrests cyclic fatigue-crack propagation.

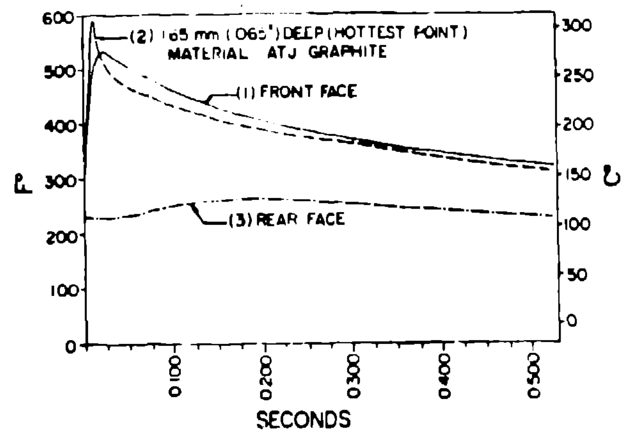

Fig. 3. FMIT beamstop temperature fluctuation.

Water-Cooling Passages

In the prototype, heat fluxes are higher than in the final FMIT version. As a design criteria, it was decided that boiling was to be avoided, and boiling heat transfer would be used only in an overload condition. Therefore, it is desirable to keep the cooling-passage wall temperature below the saturation point of the water (the water is maintained at a pressure above atmospheric, to elevate boiling temperature).

In the prototype, a single row of closely spaced circular passages near the graphite face is used. Swirl tapes will be incorporated to increase the heat-transfer coefficient from the water to the passage walls. By using swirl tapes, heat-transfer coefficients are nearly doubled, thus halving ΔT between bulk water temperature and the wall temperature, and providing the ability to accept a higher heat flux without boiling.

In the final FMIT version, the average heat flux is lower, and variations in the heat flux because of the pulses are well dampened by the time they reach the water passages. In this case, rows of grooves will be cut in a copper plate on its rear side near the graphite facing side. A thicker copper plate will then be brazed onto the back of this plate, to form the rear wall of the grooved passages and to give structual strength against vacuum loads and thermal distortions.

These passage geometries have undergone analysis using the code HEAT, a two-dimensional matrix finite-element code developed by R. C. Potter. The groove-geometry heat-transfer coefficients have been tested and verified by R. C. Potter and L. B. Dauelsberg.

Both plates will have water flow distributed by manifolding passages on the edges of the copper backing plates, and will be contained within the plate, with some manifolding outside the plate. The flow will be distributed so that it is greatest, and makes only a single pass, in the center of the beam where heat fluxes are highest, and there will be less flow and multiple water passes at the edges.

Conclusion

The FMIT and FMIT prototype beamstops will handle a high amount of power. Beam configuration, diagnostic, vacuum, irradiation, thermal, structual and water-flow considerations must be taken into account and integrated into a working system.